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Work by Prof. Oppenheim and Prof. Baggeroer and their collaborators is summarized here

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Adaptive Array Processing in Uncertain Inhomogeneous Media
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This report summarizes the effort performed under the grant "Adaptive Array Processing in Uncertain Inhimogeneous Media" during the past year. The format of the report is a compilation of the theses, presentations and journal articles with copies of their abstracts which have been supported all or in part by the grant. The full texts have been sent to the program manager during the year as they were written.

Presentations and Conference Proceedings

[1] A.B. Baggeroer and W.A. Kuperman, "Matched Field Processing in Ocean Acoustics," an invited lecture at the NATO - Advanced Study Institute, *Proceedings of Signal Processing and Ocean Acoustics*, Maderia, Portugal, July, 1992.

Publications in Reviewed Journals

[1] A.B. Baggeroer, W.A. Kuperman, and P.N. Mikhalevsky, "An Overview of Matched Field Methods in Ocean Acoustics" an invited article to appear in *IEEE Journal on Oceanic Engineering: Special Issue on Sonar Signal Processing*, October 1993.

[2] E. Weinstein, M. Feder and A.V. Oppenheim, "Multi-Channel Signal Separation by Decorrelation," to appear in *IEEE Transactions on Signal Processing*, August, 1993. Also technical report RLE TR-573, Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, MA 02139; June, 1992.

[3] E. Weinstein, A.V. Oppenheim, M. Feder and J.R. Buck, "Iterative and Sequential Algorithms for Multi-Sensor Signal Enhancement", to appear in *IEEE Transactions on Signal Processing*, March, 1994.

[4] G.W. Wornell, "Wavelet-Based Representations for the 1/f Family of Fractal Processes," to appear in *Proceedings of the IEEE*, Special Issue on Applications of Fractals in Electrical Engineering, September, 1993.

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AN OVERVIEW OF MATCHED FIELD METHODS IN OCEAN ACOUSTICS *

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ABSTRACT.

Recent array processing methods for ocean acoustics have utilized the physics of wave propagation as an integral part of their design. The physics of the propagtion leads to both improved performance and to algorithms where the complexity of the ocean environment can be exploited in ways not possible with traditional plane wave based methods. These methods based upon solutions of the wave equation have become known as matched field methods. Matched field processing (MFP) is a generalized beamforming method which uses the spatial complexities of acoustic fields in an ocean waveguide to localize sources in *range, depth and azimuth* or to infer parameters of the waveguide itself. It has experimentally localized sources with accuracies exceeding the Rayleigh limit for depth and the Fresnel limit for range by two orders of magnitude. MFP exploits the coherence of the mode/multipath structure and it is especially effective at low frequencies where the ocean supports coherent propagation over very long ranges. This contrasts with plane wave based models which are degraded by modal and multipath phenomena and are generally ineffective when waveguide phenomena are important. MFP is a spatial matched filter where the correlation signal, or replica, is determined by the Green's function of the waveguide. It can have either conventional or adaptive formulations and it has been implemented with an assortment of both narrowband and wideband signal models. All involve some form of correlation between the replicas derived from the wave equation and the data measured at an array of sensors. Since the replica generally has a complicated dependence upon the source location and environmental parameters, the wave equation must be solved over this parameter space. One can view MFP as an inverse problem where one attempts to invert for these dependencies over the parameter space of the source and the environment. There is currently a large literature discussing many theoretical aspects of MFP and this is supported by numerous simulations; several experiments acquiring data for MFP now have been conducted in several ocean environn ¬nts and these have demonstrated both its capabilities and some of its limitations. Consequently, there is a modest understanding of both the theory and the experimental capabilities of MFP. This article provides an overview of both.

Multi-Channel Signal Separation by Decorrelation

Ehud Weinstein   Meir Fedei   Alan V. Oppenheim

December 9, 1992

In a variety of contexts observations are made of the outputs of an unknown multiple-input multiple-output linear system, from which it is of interest to identify the unknown system and to recover the input signals. This often arises, for example, with speech recorded in an acoustic environment in the presence of background noise or competing speakers, in passive sonar applications, and in data communications in the presence of cross-coupling effects between the transmission channels. In this paper we specifically consider the two-channel case in which we observe the outputs of a 2x2 linear time invariant system. Our approach consists of reconstructing the input signals by assuming that they are statistically uncorrelated, and imposing this constraint on the signal estimates. In order to restrict the set of solutions, additional information on the true signal generation and/or on the form of the coupling systems is incorporated. Specific algorithms are developed and demonstrated for the case in which the coupling systems are discrete-time causal finite impulse response (FIR) filters. As a special case, the proposed approach suggests a potentially interesting modification of Widrow's least squares method for noise cancellation, when the reference signal contains a component of the desired signal.

Iterative and Sequential Algorithms for Multi-Sensor Signal Enhancement

E. Weinstein   A.V. Oppenheim   M. Feder   J. R. Buck

Abstract

In problems of enhancing a desired signal in the presence of noise, multiple sensor measurements will typically have components from both the signal and the noise sources. When the systems that couple the signal and the noise to the sensors are unknown, the problem becomes one of joint signal estimation and system identification. In this paper we specifically consider the two-sensor signal enhancement problem in which the desired signal is modeled as a Gaussian autoregressive (AR) process, the noise is modeled as a white Gaussian process, and the coupling systems are modeled as linear time-invariant finite impulse response (FIR) filters. Our primary approach consists of modeling the observed signals as outputs of a stochastic dyna... linear system, and we apply the Estimate-Maximize (EM) algorithm for jointly estimating the desired signal, the coupling systems, and the unknown signal and noise spectral parameters. The resulting algorithm can be viewed as the time-domain version of our previously suggested frequency-domain approach [4], where instead of the noncausal frequency-domain Wiener filter we use the Kalman smoother. This time-domain approach leads naturally to a sequential/adaptive algorithm by replacing the Kalman smoother with the Kalman filter, and in place of successive iterations on each data block the algorithm proceeds sequentially through the data with exponential weighting applied to allow adaption to nonstationary changes in the structure of the data. A computationally efficient implementation of the algorithm is developed by exploiting the structure of the Kalman filtering equations. An expression for the log-likelihood gradient based on the Kalman smoother/filter output is also developed and used to incorporate efficient gradient-based algorithms in the estimation process.

Wavelet-Based Representations for the $1/f$ Family of Fractal Processes

Gregory W. Wornell

January 16, 1992

Abstract

The $1/f$ family of fractal random processes model a truly extraordinary range of natural and man-made phenomena, many of which arise in a variety of signal processing scenarios. Yet despite their apparent importance, the lack of convenient representations for $1/f$ processes has, at least until recently, strongly limited their popularity. In this paper, we demonstrate that $1/f$ processes are, in a broad sense, optimally represented in terms of orthonormal wavelet bases. Specifically, via a useful frequency domain characterization for $1/f$ processes, we develop the wavelet expansion's role as a Karhunen-Loève-type expansion for $1/f$ processes. As an illustration of potential, we show that wavelet-based representations naturally lead to highly efficient solutions to some fundamental detection and estimation problems involving $1/f$ processes.

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